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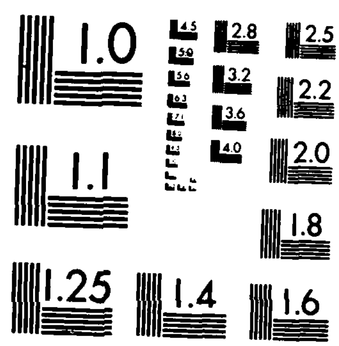

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CONTACT LENS WEAR FOR VISUAL DISORDERS IN USAF AVIATORS

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Progress Report for Period January 1968 - March 1986

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USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
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NOTICES

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This report has been reviewed and is approved for publication.

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Contact lenses are an alternative method to spectacles for correcting refractive errors, but the U.S. Air Force prohibits the wearing of contact lenses by all aircrew members unless medically or optically indicated (AFR 167-3). The USAF School of Aerospace Medicine has a clinical contact lens study consisting of 55 individuals wearing contact lenses for eye defects such as keratoconus, aphakia, anisometropia, and other special indications. Of these 55 subjects, 33 had medical conditions affecting their vision and were unconditionally grounded. Thirty-one of these individuals (18 of 19 pilots, 8 of 9 navigators, 5 of 5 other categories) were visually rehabilitated and returned to full flight status by the use of contact lenses. Hard lenses were used in 70% of the cases, and soft lenses were used in 30%. The large number of USAF aviators required to wear spectacles and new head-borne equipment has created compatibility problems with the standard USAF aviators' spectacle. For this spectacle compatibility problem, contact lenses appear as a viable alternative. However, concerns remain about the potential aviation hazards, such as $+G_z$ effects, bubble formation, and corneal hypoxia.

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CONTACT LENS WEAR FOR VISUAL DISORDERS IN USAF AVIATORS

INTRODUCTION

The most important of the senses used in aviation and aerospace operations is sight. Any factor affecting sight--environmental, medical, optical--is important to the aviator. Eye defects, and especially refractive errors, eliminate a large number of otherwise acceptable candidates for flying. Elimination of these defects would immeasurably increase the pool of available candidates for aviation.

Visual standards for pilots (USAF Class I) screen out all but those with minimal refractive errors. Classes II and III visual standards are much more liberal. Even with careful screening, however, the refractive status of the human eye changes with age. These changes could shorten the flying careers of many if corrective lenses were not used (1). Glass and plastic spectacle lenses have been the accepted way for correcting refractive errors. The advent of contact lenses brought an entirely new concept in the correction of refractive errors for both the aviator as well as the general public.

The use of contact lenses to correct refractive errors is not a new idea. The idea, in fact, is quite old, but as in many other cases, the "state of the art" was not up to the idea at the time. Leonardo da Vinci originally suggested the idea of using corrective lenses (2, 3). Later, in 1801, Sir Thomas Young, who was astigmatic, actually placed a small appliance on his cornea to correct his astigmatism. The appliance, called a hydrodiascope (4), was a one-quarter-inch long tube filled with water and a tiny lens set at its front end. The open end was smoothed with wax and touched to the cornea. In 1827, Sir John Herschel wrote a theoretical treatise on contact lenses (5). In 1887, Muller of Wiesbaden made a glass contact lens to be worn as a protective device (6). A year later, Dr. A. E. Fick of Zurich, Switzerland, first used the term "contact lens" (Kontackbrille) (7). In 1929, Heine realized that the fluid between the contact lens and cornea nullified the refraction of the latter and that the eye then took the refraction of the contact glass (8). The real breakthrough came in the fall of 1938, when molded plastic lenses and refined fitting techniques were introduced by Obrig and Salvatori in the United States (9). These lenses, made of polymethyl methacrylate (PMMA), were molded and optically corrected scleral lenses (Fig. 1). The PMMA material is still used today for the hard contact lenses. The plastic had numerous advantages over the glass previously used in making contacts; it weighed only 40% as much as the glass, had an index of refraction of 1.495, did not scratch too easily, and had transmission characteristics almost identical to glass.

In 1948, Tuohy produced the first corneal lens in America (10) (Fig. 2). Refinements and improvements have been made in this type of lens and in fitting techniques, and this micro or corneal lens is still fitted today as a hard contact lens. In 1968, a soft contact lens material, hydroxyethyl methacrylate (HEMA), was introduced in Czechoslovakia (11). Since then, numerous changes and refinements have been made in this hydrophilic material, and it is the only lens material approved by the Food and Drug Administration for extended/overnight wear. Other hard materials have been developed for contact

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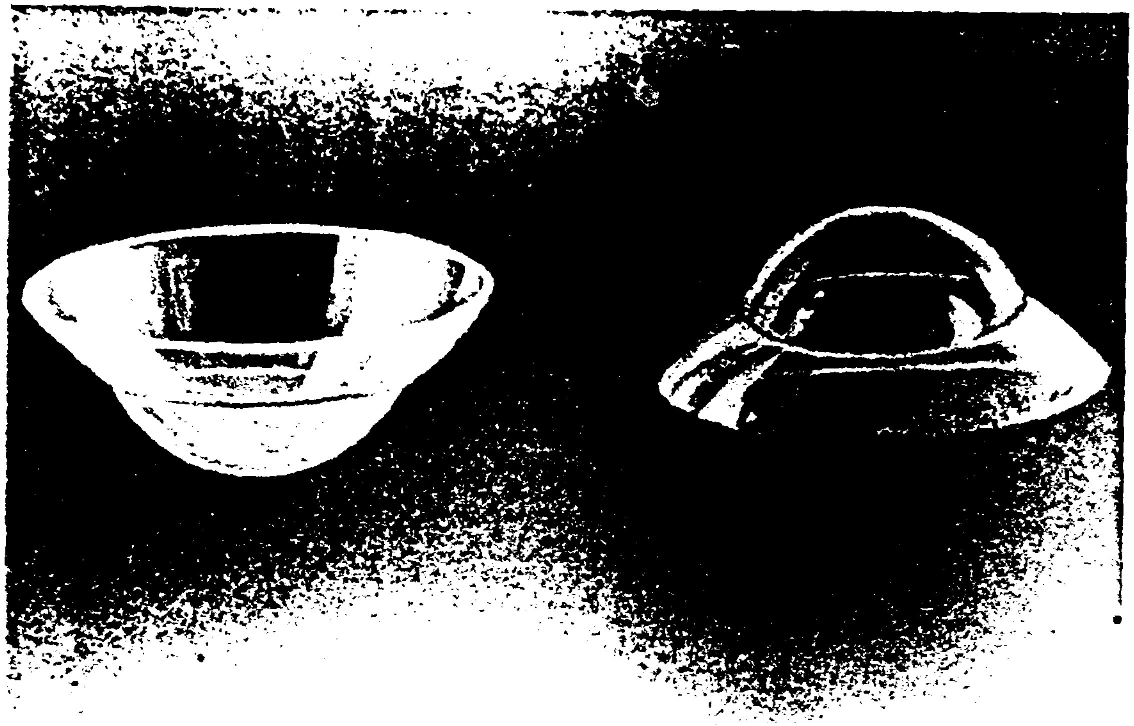

Figure 1. Scleral contact lenses.

Figure 2. Corneal contact lenses.

lenses, thus making the entire contact lens field a bit more complicated and exciting than when there was only the hard (PMMA) type of contact lens. Some other rigid materials are now in use, such as silicone/acrylate polymers, the so-called "hard, gas-permeable" lenses. The history of contact lenses is summarized in Figure 3.

1500 LEONARDO da VINCI.........IDEA

1801 THOMAS YOUNG............HYDRODIASCOPE

1827 SIR JOHN F.W. HERSCHEL..MOLD OF EYE

1887 F.A. MULLER............. BLOWN GLASS SHELL

1888 DR. A.E. FICK............(KONTACKBRILLE)

1929 PROFESSOR HEINE.......LIQUID LENS

1938 OBRIG AND SALVATORI.....METHYL METHYCRYLATE LENS

1948 KEVIN TUOHY...........CORNEAL CONTACT LENS (MICRO LENS)

1960 F. RIDLEY..............FLUSH FITTING SCLERAL LENS

1968 SOFLENS (B & L)........HYDROPHILIC (POLYMACON)

Figure 3. History of contact lenses.

BACKGROUND

If the manpower pool contained a sufficient number of emmetropic individuals and if the refractive status remained static throughout adult life, then there would be no need for contact lenses, nor, in fact, for spectacles until one became presbyopic; this, however, is not the case. Liberalized aircrew selection policies, an increasingly myopic candidate pool, and pathologic eye defects make the topic of contact lenses much more significant.

The eye can be considered a single refractive system of approximately 60 diopters (D) (Fig. 4). Because of the curvature and index of refraction, about two-thirds of the bending of the light occurs at the cornea (+45 D) and the remaining amount by the intraocular lens (+15 D). A hard contact lens abolishes the anterior surface of the cornea as the initial refractive surface and substitutes a new curvature produced by the anterior surface of the contact lens itself (Fig. 5). The posterior surface of the contact lens must be made to fit the corneal curvature as exactly as possible. Hard spherical contact lenses correct astigmatism by creating a tear lens that optically eliminates the toric surface of the cornea (Fig. 6). The tear lens also fills in any irregularities of the epithelial surface. For this reason, scarred, irregular,

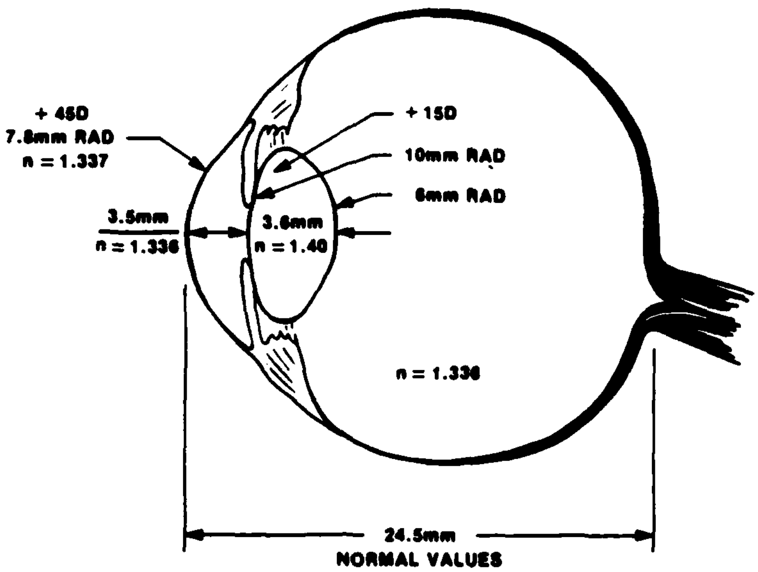

Figure 4. Normal values for the optical components of the human eye.

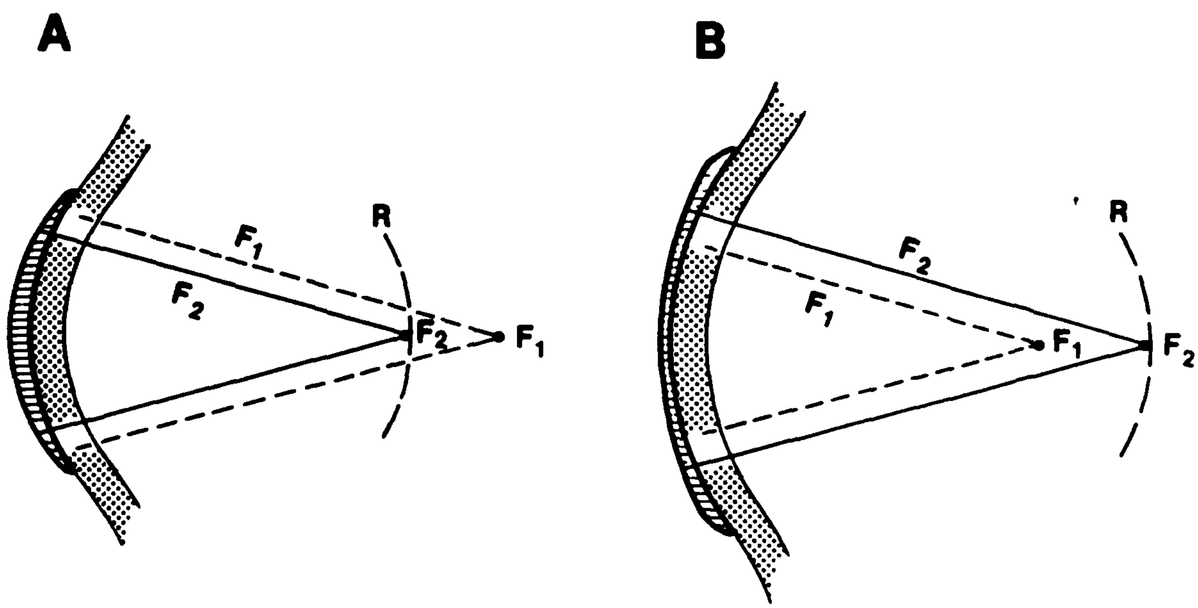

Figure 5. Corneal contact lens correction of refractive errors.
A - correction for hyperopia; B - correction for myopia.

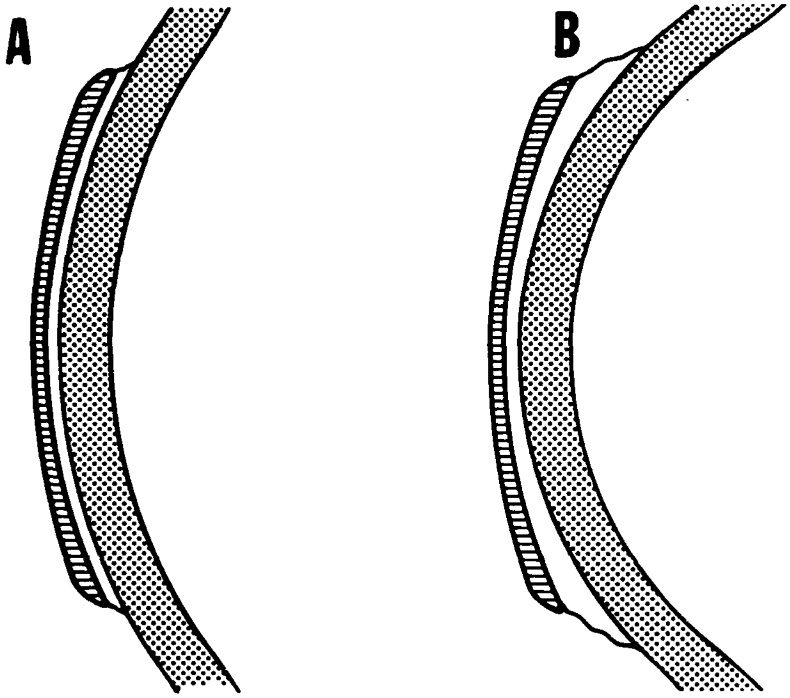

Figure 6. Tear lens created between the cornea and a contact lens, eliminating the toric surface of the cornea. A - same curvature as the cornea; B - flatter fitting lens.

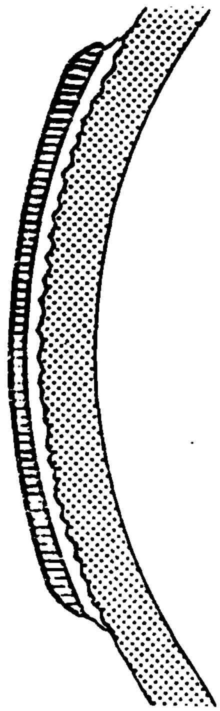

Figure 7. Contact lens created tear lens filling in corneal surface irregularities.

and keratoconic corneas with resulting poor spectacle vision may often show markedly improved vision with a hard contact lens in place (Fig. 7).

However, hard contact lenses require a significant adaptation period before they are adequately tolerated. They also may cause refractive/corneal changes that result in blurred spectacle vision. Additionally, they are more easily dislodged from the eye than soft contact lenses, and are prone to disabling subcontact lens foreign bodies in dusty environments. Polymethyl methacrylate lenses are impermeable to oxygen.

Soft contact lenses contain a large percentage of water (38%-79%) and are gas permeable and flexible. Since the lenses are flexible, they do not correct astigmatism without special modifications. The lenses are immediately comfortable, center well, and are not easily dislodged from the eye. The visual acuity from soft lenses is often not as good as with hard lenses or spectacles.

RATIONALE FOR CONTACT LENS USE

The use of contact lenses in aviation necessitates that we look at all aspects of the problem. In essence, the advantages vs. the disadvantages must be weighed --

Advantages:

- An increase in the size of the field of vision
- Good vision in inclement weather
- No lens fogging
- Elimination of reflection from the spectacle lens
- No interference with the use of optical instruments, such as helmet-mounted target sights
- Perspiration problems eliminated
- Compatibility with life support and personal protective gear
- Specific treatment for certain medical/optical conditions: keratoconus, irregular astigmatism, aphakia, anisometropia

Disadvantages:

- Some individuals cannot tolerate contact lenses
- Poorer visual acuity than with spectacles, especially with use of soft contact lenses
- Bubbles may form beneath the lens at altitude

- High-G forces may dislodge the lenses, especially hard lenses

- Lenses may be dislodged or lost for other reasons

- More difficult and time-consuming to fit than spectacles

- Professional eye care needed for fitting and follow-up is an added burden to the medical care system

- Foreign bodies (dusty environment) under lens would compromise lens wear (worse with hard lenses)

- Lens hygiene/replacement difficult in field situations

- Refractive/corneal changes possible with hard contact lenses

- Cornea more prone to edema (refraction changes) in hypoxic environments (altitude) while wearing contact lenses

- Adaptation/wearing-time problems with hard contact lenses

- In chemical warfare environment, first act as a barrier, then as a sponge to prolong chemical effects (Flynn, unpublished observations)

- Decrease in visual acuity with spherical soft lenses if there is over 0.75 D of astigmatism

- Cost in time and money increased as compared to spectacle fitting and follow-up

- No ocular protection from blunt trauma and flying debris as afforded by spectacle lenses

Careful consideration of these factors and others have brought about the present USAF policy for aviators that contact lenses are not used as a cosmetic replacement for spectacles. The use of these devices is recognized and authorized for medical, optical, and certain special indications. The Ophthalmology Branch at the USAF School of Aerospace Medicine (USAFSAM) approves and fits all contact lenses used by USAF aviators.

USAFSAM CLINICAL EXPERIENCE WITH CONTACT LENSES

The U.S. Air Force first began to show serious interest in contact lenses in 1950. At that time, 21 subjects, most of whom were on flying status, were fitted with corneal lenses. The lenses were poorly tolerated by all the subjects, and all discontinued wearing the lenses in a short period. A second research effort was undertaken in 1955; vented plastic scleral lenses were chosen. Sixty-four pilots and navigators were fitted and studied from 1955 to 1958. The fitting technique was discovered to be too involved and time-consuming. Numerous visits and refittings were necessary, and it was concluded that this type of lens was not satisfactory. Improved corneal lens designs stimulated another study which started in 1959. In this case, 82 USAF flying personnel were selected and fitted with corneal contact lenses. By

1960, only 50% of the original number were still wearing their lenses, and by 1965, only 3 of the original 82 were still wearing their contact lenses (12).

The present USAFSAM Clinical Contact Lens Study Group consists totally of individuals who are wearing contact lenses for medical, optical, and certain special indications. There are 55 individuals in the USAFSAM Contact Lens Study Group and the group is composed of 19 pilots, 9 navigators, and 27 other flyers. The indications for which these contact lenses are being worn are as follows:

- Aphakia - 22 (10 pilots, 3 navigators, 9 others) (Table 1)

- Keratoconus - 13 (9 pilots, 2 navigators, 2 others) (Table 2)

- Miscellaneous - 20 (1 herpes keratitis/navigator, 1 irregular astigmatism/navigator, 2 anisometropias/navigators, 2 enhanced job performance/aerial photographer and flight engineer for night vision goggle use, and 14 excessive refractive errors)

Of the 55 individuals in this study group, 33 presented directly to the USAFSAM Ophthalmology Branch for medical conditions affecting their vision so that they were all to be unconditionally grounded. Twenty-six pilots and navigators (18 of 19 pilots and 8 of 9 navigators) were visually rehabilitated and returned to full flight status by the use of contact lenses (Table 3). The use of contact lenses by these individuals is not just desirable, it is an absolute necessity, for a significant savings accrues to the government, both operationally and economically. There is a strong personal motivational factor that obviously plays an important part in the success of these particular individuals. Hard lenses were used in 70% of the cases and soft lenses were used in 30% of the cases. All 13 subjects of the keratoconus cases necessitated the use of hard contact lenses, since soft contact lenses do not correct the corneal irregularities found in this condition. Waivers were granted to return to flying duties for 51 of the 55 subjects in the study group. Four were not granted waivers, but the reason was due to other medical conditions, such as cardiac or neurologic problems.

A research project on the "Use of Soft Contact Lenses in the Aviation Environment" is underway at USAFSAM. New generation chemical/biological life support gear, night vision goggles, eye protective devices, and helmet-mounted target sights have created serious compatibility problems with aircrew spectacle frames. The compatibility problem, with the large number of aviators wearing spectacles--20% of the pilots and 50% of the navigators in the U.S. Air Force (1)--has prompted this investigation into the feasibility of soft contact lens wear by USAF aviators.

TABLE 1. APHAKIC CONTACT LENS WEAR

Subject	Aircraft	Contact lens		Waiver	Duration (yrs)
Pilot	C-5	hard	O.S.	yes	4
Pilot	T-39	hard	O.D.	yes	1
Pilot	B-52	hard	O.U.	yes	2[b]
Pilot	T-39	hard	O.U.	no[a]	---
Pilot	F-4	soft	O.S.	yes	2[b]
Pilot	F-100	hard	O.D.	yes	2
Pilot	T-39	hard	O.S.	yes	6
Pilot	F-111	soft	O.D.	yes	3
Pilot	B-52	hard	O.U.	yes	2
Pilot	KC-135	soft	O.S.	yes	6[b]
Navigator	C-141	soft	O.S.	no[a]	---
Navigator	F-111	soft	O.D.	yes	4[b]
Navigator	F-4	soft	O.S.	yes	2[b]
Loadmaster	C-141	hard	O.S.	yes	2
Loadmaster	C-5	soft	O.D.	yes	2
Loadmaster	C-141	soft	O.D.	yes	6[b]
Loadmaster	C-5	soft	O.U.	yes	3[b]
Loadmaster	C-141	soft	O.S.	yes	3
Loadmaster	C-5	hard	O.D.	yes	3[b]
Flight engineer	C-5	hard	O.S.	yes	4[b]
Flight engineer	C-141	hard	O.S.	yes	5[b]
Gunner	B-52	hard	O.S.	yes	10

[a]Flying waiver denied for other health reasons

[b]Presently active

TABLE 2. KERATOCONIC CONTACT LENS WEAR

Subject	Aircraft	Contact lens	Waiver	Duration (yrs)
Pilot	C-141	O.S.	yes	8
Pilot	KC-135	O.U.	yes	2[d]
Pilot	C-141	O.U.	yes	12[d]
Pilot	U-6	O.S.	yes	10
Pilot	C-141	O.D.	yes/no[a]	2
Pilot	A-10	O.S.	yes	16[d]
Pilot	F-106	O.D.	yes	8[d]
Pilot	F-4	O.S.	yes	7
Pilot	B-52	O.S.	yes	9[d]
Navigator	KC-135	O.U.	yes	8[d]
Navigator	C-130	O.U.	yes/no[b]	8
Flight engineer	C-141	O.U.	no[c]	-
Flight surgeon	AT-38	O.U.	yes	2[d]

[a]Required keratoplasty

[b]Developed contact lens intolerance

[c]Flying waiver denied for other health reasons

[d]Presently active

TABLE 3. CONTACT LENS WEAR

	Pilot	Navigator	Other
Hard lens	16	6	15
Soft lens	3	3	12
Total	19	9	27
Returned to flying status	18	8	25

Presently, there are 3 major concerns for contact lens use in the aviation environment:

1. The potential for lens decentration and dislodgement during periods of aircraft acceleration generating high gravitational (G) forces. Increased G forces from acceleration are common in today's high-performance aircraft. For contact lens wear, acceleration that generates high-G forces is especially a concern for forces tangential to the cornea, such as along the z-axis (G_z). The validity of this concern was demonstrated in previous investigations that revealed that significant lens decentration may occur with hard contact lenses under six times the normal force of gravity ($+6G_z$)(Tredici, unpublished observations).

2. The possibility of subcontact lens bubble formation due to low atmospheric pressure. Subcontact lens bubble formation from low atmospheric pressure was reported by Jaeckle as early as 1944 (13). After many advances in contact lens fitting and design characteristics, Newsom et al. found bubble formation in 66% of 16 PMMA wearers tested (14). With the advent of soft hydrophilic lenses, the new property of gas permeability was introduced to contact lens practitioners. As a result of this gas permeability, subcontact lens bubbles have not been reported at tested altitudes as high as 37,000 ft (15, 16, 17).

3. The potential for corneal edema due to the reduction in atmospheric oxygen available for normal corneal metabolism. Since the cornea is an avascular tissue, its primary open-eye source of oxygen is from the ambient air. At sea level, the oxygen partial pressure of this source is about 155 mmHg and decreases exponentially with increasing altitude. For instance, at an air altitude of 10,000 ft, the oxygen partial pressure is reduced to 109 mmHg and to 59 mmHg at 25,000 ft. A contact lens placed between this source and the cornea must possess sufficient oxygen transport properties to meet an 11 to 19 mmHg oxygen-critical anterior corneal level to prevent hypoxia and permit a normal state of corneal hydration (18).

Each of these unique contact lens hazards of the aviation environment will be subjects of future reports from our laboratory.

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